A cylindrical GEM detector for BES III

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Outline

• The BESIII experiment and the MDC ageing problem
• The Cylindrical GEM Inner Tracker: requirements and operation
• Estimation of the Inner Tracker expected background
• Computing simulation for detector optimization
• Validation of the simulation with a Beam Test
The BES III experiment - 1

- The BESIII experiment is located at the Beijing $e^+e^-$ collider (BEPCII) that works in the energy range from 2 to 4.6 GeV
- At least 7 more years of data taking
- The physics program includes:
  - High statistics studies of light hadron and charmonium spectroscopy
  - Studies of charm physics
  - Studies of $\tau$ physics
  - High precision test of EW interaction
Observation of charged exotic state

Quark quartet opens fresh vista on matter
First particle containing four quarks is confirmed.

Devin Powell
18 June 2013
The BES III experiment - 2

- BESIII is a multipurpose magnetic spectrometer with an effective geometrical acceptance of 93% of $4\pi$.
- The Italian groups proposed the replacement of the inner part of the drift chamber that is losing efficiency for aging effect with 3 layers of cylindrical GEM.
- Now an international group is developing the CGEM-IT.
The Multilayer Drift Chamber

- MDC tracks low momentum particles and performs momentum and dE/dx measurement to identifying charged particles.
- Spatial resolution is 130 μm in r-ϕ plane and 2 mm in the z-coordinate.
- The cell consists of a sense wire surrounded by 8 field wires.
- MDC contains 43 sense wire layers (1-8 inner MDC and 9-43 outer MDC) with different stereo angle.
- Inner and Outer MDC are two separate chambers sharing the same gas volume.
MDC ageing issue

- Due to beam background and luminosity increase, the inner chamber of the MDC shows ageing effect.

- The gain of the cells of these detector is decreasing up to 25% for the first layer.

- Being BESIII an experiment that has to take data at least 7 more years, the inner part of the MDC has to be changed with a new and more performing inner tracker.
CGEM in a nutshell

- Gas detector uses high voltages to drift and to increase the electron numbers in the hole region where the E field reaches values of $10^5$ V/cm

- Thanks to its geometry a gain of $10^4$ is achieved in gas mixture, such as Argon/CO$_2$ (70:30)

- Charge deposited is readout by the anode circuit, performing a 2-D readout
A CGEM based Inner Tracker

Kloe 2 has performed the first cylindrical triple GEM

- Induction
- Transfer 2
- Conversion & drift
- Transfer 1
- Anode
- GEM3
- GEM2
- GEM1
- Cathode

Green bars show the CGEM active area

BESIII requirements

- Rate capability: \( \sim 10^4 \text{ Hz/cm}^2 \)
- Spatial resolution:
  
  \[ s_{xy} \sim 100\mu\text{m} : s_z \sim 1\text{mm} \]
- Momentum resolution:
  
  \[ s_{pt}/P_t \sim 0.5\% @1\text{GeV} \]
- Efficiency = \( \sim 98\% \)
- Material budget
  
  \( \leq 1.5\% \, X_0 \) in all layers
- Coverage: 93\% 4\pi
- Inner (Outer) radius:
  
  78 mm (178 mm)
Innovations and peculiarities

- Several innovation will be implemented to improve the detector with respect to the state of art and to achieve the BESIII requirements:
  - Rohacell: a lighter material for the mechanical structure;
  - Anode design: the jagged mode;
  - Analog readout.
Construction technique - 1

- GEM foils are produced by the CERN EST-DEM workshop as polymide foils, 50 μm thick, with a copper cladding of 3 μm on the internal surfaces;
- Two GEM foils are spliced together in order to realize one single electrode;
- A cylindrical mould is used to shape the detector foils.
Construction technique - 2

- Cathode electrode and anode circuit are build similarly and are glued onto a kapton (12,5 μm) - rohacell (1 mm) double sandwich
- The mechanical support is performed by annular flanges of permaglass placed on the edges of the cylinder
- A vertical insertion system is used to assemble the full layer from the 5 electrode sub-layers
Construction technique - 3

Kapton \([12.5 \, \mu m]\)  
\[= 0.004375 \, X_0\]

Rohacell \([1.0 \, mm]\)  
\[= 0.007 \, X_0\]

Structure weight (without circuit) = 180 g  
\[= 0.02275 \, X_0\]
## Schedule and funding

<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2018</td>
<td>commissioning and data taking</td>
</tr>
<tr>
<td>2017</td>
<td>installation</td>
</tr>
<tr>
<td>2016</td>
<td>QA and test complete construction</td>
</tr>
<tr>
<td>2015</td>
<td>begin detector construction</td>
</tr>
<tr>
<td></td>
<td>finalize the detector design</td>
</tr>
<tr>
<td>2014</td>
<td>R&amp;D and simulation for detector design</td>
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</table>

The project has been recognized as a **Significant Research Project** within the Executive Program for Scientific and Technological Cooperation between Italy and P.R.C., and recently selected as one of the project **funded by the European Commission within the call H2020-MSCA-RISE-2014**.
Thesis outline

Detector optimization

Background studies

Detector simulations

Beam Test

Geant4 full-detector simulation

this thesis work
Background studies
Background studies

- Background studies are performed to optimize the front-end electronics.
- The occupancy of the strips of the CGEM-IT is extracted from the MDC random trigger in BESIII and a Monte Carlo simulation is used to take into account different geometry and material.

\[
R_{GEM}^{exp}(r) = R_{MDC}^{data}(r) \times \frac{R_{GEM}^{MC}(r)}{R_{MDC}^{MC}(r)}
\]
Background studies

- Background level is calculated for runs belonging to different periods and energy beam.
- The expected CGEM rate/strip for the innermost layer is about 9.5 kHz.
- A safety factor x6 is considered and 60 kHz/strip is the maximum rate considered for the electronics design.
Detector simulation response

Geometry description and gas studies
Simulation of detector response from ionization to collection
Extrapolation of the hit digitization parameters
Garfield detector simulation

- Garfield is a toolkit for detailed computational simulation which uses additional tools, such as:
  - Magboltz that solves the equations for electrons in gas mixtures;
  - Heed that generates ionization patterns of fast charged particles;
  - Ansys, a finite element simulation software that computes the electric field in the space node-by-node.
Garfield simulation

- Charged ionizing particles are simulated through the detector.
- Electron avalanche drifts to the anode plane and its spatial distribution is studied.
- Using the fit of these plots, information for hit digitization are extracted.
- Several events are simulated to extract a mean value in different configurations, i.e. the magnetic field.
- The magnetic field shifts the distribution of few mm and broads it.
Garfield simulations

- In addition to the baseline design, other configurations with different gas mixture and conversion gap have been simulated for a comparison with the beam test results.

- Fit to the charge distributions are collected and their mean value is used as preliminary result to be compared to the beam test result.

<table>
<thead>
<tr>
<th>Gas</th>
<th>Conversion Gap</th>
<th>Magnetic field (T)</th>
<th>$\Delta X$ ($\mu$m)</th>
<th>Lorentz angle ($^\circ$)</th>
<th>Cluster multiplicity</th>
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<tbody>
<tr>
<td>Argon-CO$_2$</td>
<td>3</td>
<td>0</td>
<td>38 ± 72</td>
<td>/</td>
<td>1.9</td>
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<tr>
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<td>0</td>
<td>-10 ± 65</td>
<td>/</td>
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<tr>
<td>Argon-C$<em>4$H$</em>{10}$</td>
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<td>/</td>
<td>2.6</td>
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<td>/</td>
<td>2.5</td>
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<tr>
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<td>1</td>
<td>3131 ± 357</td>
<td>20.3</td>
<td>3.6</td>
</tr>
<tr>
<td>Argon-C$<em>4$H$</em>{10}$</td>
<td>5</td>
<td>1</td>
<td>3558 ± 675</td>
<td>18.9</td>
<td>3.8</td>
</tr>
</tbody>
</table>
Beam Test

Purpose and setup

Algorithm and reconstruction

Results
Purpose and measurement

• The purpose of the beam test is:
  – Validate GEM analog readout in magnetic field.
  – Validate Garfield simulation and extract information for hit digitization.

• We performed the following measurements with a 3/2/2/2 mm and 5/2/2/2 mm GEM geometries:
  – Spatial resolution as function of the magnetic field
  – Cluster size as function of the magnetic field
  – Efficiency measurements in a gain range of 2k - 22k
  – Test different gas mixtures: Argon/CO\textsubscript{2} (70/30) and Argon/Isobutane (90/10)
  – Different incident beam angle: 0°/10°/30°/45° in B field
• The BESIII test chamber, the tracking telescope and the trigger system are placed in line, inside a dipole magnet.

• Data are acquired by Scalable Readout system and the front-end is gave by APV25 hybrid board

• The HV is provided by CAEN power supplies and the gas is supplied by premixed bottles
Beam Test results

- Pedestal studies are performed to suppress the background
- Digitizer and clusterizer algorithm have been developed to reconstruct the particle trajectory as a 2-D clusters with deposited charge and position information
- Calibration and threshold optimization are performed
- Tracking algorithm is used to align the different planes and to measure the resolution as the width of the fit to the residual distribution
- Up to now only Argon/Isobutane data have been studied
Efficiency vs Gain (no B field)

Efficiency plateau is reached at a gain of 6500
Cluster size (no B field)

Cluster Size vs gain

- The cluster multiplicity ranges from 1.9 to 4, showing a non equal charge sharing.

- The behaviour is linear at low gain while at higher gains the linearity is lost due to saturation of the front-end amplifier.
The spatial resolution without magnetic field reaches a value of about 90 μm at a gain of 6500.
Measurement in B field
Measurement in B field

- Preliminary results from the data with magnetic field will be presented since data analysis is still ongoing.
- Only one coordinate is affected by the magnetic field.
- The field shifts the avalanche and produces an increasing of the diffusion.
Efficiency vs Gain for different field

- Y view - B = 0 T
- Y view - B = 0.5 T
- Y view - B = 1.0 T
Cluster size in B field

- No significant B field effect affects the parallel view.
- Orthogonal view shows an increasing of the cluster size and the distribution depart from a Gaussian shape.
The cluster size increases linearly with the magnetic field.

5 mm and 3 mm configuration are compared with Garfield simulations: different slopes are due to wrong HV parameters for the BESIII test chamber which has increased the Lorentz angle and the avalanche broadening.
Summary and Outlook
Summary

- A new Inner Tracker for BESIII, the CGEM, is under studies to optimize the design of the detector and to start building it. A contribution to the project comes from:
  - A study of the expected background on the new inner tracker has been performed combining real background events and Monte Carlo data to predict a maximum rate of 60 kHz per strip in the CGEM.
  - The shape of the electron avalanche has been studied by means of a Garfield simulation. The charge distribution width and the cluster size have been compared for different detector configurations and gas mixtures.
  - A beam test has been performed in December 2014 with a muon beam to test the GEM analog readout in magnetic field and to validate the Garfield simulation and extract input for the digitization. Several configurations have been tested with and without magnetic field.
Outlook

- This thesis provides a set of software and analysis tools that can be used to complete and extend the studies done so far. For the Garfield simulation more accurate measurements can be done to increase the statistics.

- The beam test analysis needs to be completed and a new beam test is foreseen for the end of May 2015.

- Additional innovative studies can be performed with the data acquired so far: a μTPC mode readout, that combine time and charge information, can be explored to have better precision of the cluster position.
Thanks
Backup
Argon/CO₂ (70:30) and Argon/Isobutane (90:10) gas mixtures are studied as function of the electric field.
microTPC

For the uTPC mode operation a good time resolution on single hit O(<10ns) is crucial

- APV samples signal at 25ns
- Time extracted by fitting the binned signal shape with a FD function $\sigma_t = 11-12$ ns
- Take the first hit from T1 ant T2 and compute $D_t = t1-t2$
- Intrinsically MM can do much better
  - TB at BTF: $\sigma_t = 6$ ns

Testbeam @ LNF

Time difference (ns) of earliest hits in T1 and T2

$\theta_{\text{time}} = 11.4$ ns
Fit to the charge samples to extract the drift time

Graph

\[ F_D(t) = K \frac{1}{1 + e^{-(t-t_D)/\tau_D}} + B \]

charge (a.u.)

\begin{align*}
0 & \quad 50 & \quad 100 & \quad 150 \\
-50 & \quad 0 & \quad 50 & \quad 100
\end{align*}

time (ns)

Fit to the charge samples to extract the drift time

\( \chi^2 / \text{ndf} = 176.8 / 114 \)

Constant \( 87.96 \pm 2.33 \)

Mean \( 16.66 \pm 0.24 \)

Sigma \( 12 \pm 0.2 \)

\( \sigma(t_2-t_1 \sim 12 \text{ ns}) \)

one 8-strip cluster

not always so good

\( \text{strip of the cluster} \)

\( \text{drift path (mm)} \)

\( t_0 \quad t_1 \quad t_2 \quad t_3 \quad t_4 \quad t_5 \quad t_6 \)

\( t_0 \quad t_1 \quad t_2 \quad t_3 \quad t_4 \quad t_5 \quad t_6 \)

\( \sigma(t_2-t_1 \sim 12 \text{ ns}) \)

\( X (\text{mm}) \)
Gas gain
Difference between BESIII and tracking chamber

- Gap 3 mm to 5 mm
- Ground plane from 0.2 mm to 2.0 mm away from the strip plane
- Drift gap field from 1.5 kV/cm to 0.9 kV/cm

After changing the gap from 3 mm to 5 mm we didn’t change the drift field value accordingly.